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ADVANCES IN MODERN PHYSICS:

part 1

Учебное пособие

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PREFACE

Настоящее учебное пособие включает актуальные тексты (2017-2018гг.) учебно-познавательной тематики для магистрантов физического факультета (направление 03.04.02 «Физика»).

Целью данного пособия является формирование навыков научной речи, в основе которых лежит владение характерными для научного стиля лексикограмматическими структурами. Ставится задача подготовить магистрантов к основным формам как письменного (аннотация, теоретический обзор, статья), так и устного научного общения (доклад, дискуссия).

Пособие состоит из 6 разделов, рассматривающих проблемы и достижения в сфере информационных технологий в современном мире. Каждый из них содержит аутентичные материалы (источники: *Aeon, Nautilus, Quanta Magazine, Quartz*) и упражнения к ним. Раздел “Supplementary reading“ служит материалом для расширения словарного запаса и дальнейшего закрепления навыков работы с текстами по специальности.

Пособие может успешно использоваться как для аудиторных занятий, так и для внеаудиторной практики.

1. Light dawns

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: second, theory, visit, bank, result, assistant, astronomer, typically, calculations, distance

Exercise II.

Make sure you know the following words and word combinations.

plaque, instantaneously, ensuing, fleeting, excruciating, constitute, dimension, pulsar, intriguing, QED

Light dawns

Light travels at around 300,000 km per second. Why not faster? Why not slower? A new theory inches us closer to an answer (1) (2), (3), (3), (3)

If you visit the Paris Observatory on the left bank of the Seine, you'll see a plaque on its wall announcing that the speed of light was first measured there in 1676. The odd thing is, this result came about unintentionally. Ole Rømer, a Dane who was working as an assistant to the Italian astronomer Giovanni Domenico Cassini, was trying to account for certain discrepancies in eclipses of one of the moons of Jupiter. Rømer and Cassini discussed the possibility that light has a finite speed (it had typically been thought to move instantaneously).

Eventually, following some rough calculations, Rømer concluded that light rays must take 10 or 11 minutes to cross a distance ‘equal to the half-diameter of the terrestrial orbit’. Cassini himself had had second thoughts about the whole idea. He argued that if finite speed was the problem, and light really did take time to get around, the same delay ought to be visible in measurements of Jupiter’s other moons – and it wasn’t. The ensuing controversy came to an end only in 1728, when the English astronomer James Bradley found an alternative way to take the measurement. And as many subsequent experiments have confirmed, the estimate that came out of Rømer’s original observations was about 25 per cent off. We have now fixed the speed of light in a vacuum at exactly 299,792.458 kilometres per second. Why this particular speed and not something else? Or, to put it another way, where does the speed of light come from? Electromagnetic theory gave a first crucial insight 150 years ago. The Scottish physicist James Clerk Maxwell showed that when electric and magnetic fields change in time, they interact to produce a travelling electromagnetic wave. Maxwell calculated the speed of the wave from his equations and found it to be exactly the known speed of light. This strongly suggested that light was an electromagnetic wave – as was soon definitively confirmed. A further breakthrough came in 1905, when Albert Einstein showed that c, the speed of light through a vacuum, is the universal speed limit. According to his special theory of relativity, nothing can move faster. So, thanks to Maxwell and Einstein, we know that the speed of light is connected with a number of other (on the face of it, quite distinct) phenomena in surprising ways. But neither theory fully explains what determines that speed. What might? According to new research, the secret of c can be found in the nature of empty space. Until quantum theory came along, electromagnetism was the complete theory of light. It remains tremendously important and useful, but it raises a question. To calculate the speed of light in a vacuum, Maxwell used empirically measured values for two constants that define the electric and magnetic properties of empty space. Call them, respectively, Ɛ0 and μ0. The thing is, in a vacuum, it's not clear that these numbers should mean anything. After all, electricity and magnetism actually arise from the behaviour of charged elementary particles such as electrons. But if we're talking about empty space, there shouldn't be any particles in there, should there? This is where quantum physics enters. In the advanced version called quantum field theory, a vacuum is never really empty. It is the 'vacuum state', the lowest energy of a quantum system. It is an arena in which quantum fluctuations produce evanescent energies and elementary particles. (2)

What's a quantum fluctuation? Heisenberg's Uncertainty Principle states that there is always some indefiniteness associated with physical measurements. According to classical physics, we can know exactly the position and momentum of, for example, a billiard ball at rest. But this is precisely what the Uncertainty Principle denies. According to Heisenberg, we can't accurately know both at the same time. It's as if the ball quivered or jittered slightly relative to the fixed values we think it has. These fluctuations are too small to make much difference at the human scale; but in a quantum vacuum, they produce tiny bursts of energy or (equivalently) matter, in the form of elementary particles that rapidly pop in and out of existence. These short-lived phenomena might seem to be a ghostly form of reality. But they do have measurable effects, including electromagnetic ones. That’s because these fleeting excitations of the quantum vacuum appear as pairs of particles and antiparticles with equal and opposite electric charge, such as electrons and positrons. An electric field applied to the vacuum distorts these pairs to produce an electric response, and a magnetic field affects them to create a magnetic response. This behaviour gives us a way to calculate, not just measure, the electromagnetic properties of the quantum vacuum and, from them, to derive the value of c. In 2010, the physicist Gerd Leuchs and colleagues at the Max Planck Institute for the Science of Light in Germany did just that. They used virtual pairs in the quantum vacuum to calculate the electric constant Ɛ0. This inspired Marcel Urban and colleagues at the University of Paris-Sud to calculate c from the electromagnetic properties of the quantum vacuum. In 2013, they reported that their approach gave the correct numerical value. This result is satisfying. But it is not definitive. For one thing, Urban and colleagues had to make some unsupported assumptions. It will take a full analysis and some experiments to prove that c can really be derived from the quantum vacuum. Nevertheless, Leuchs tells me that he continues to be fascinated by the connection between classical electromagnetism and quantum fluctuations, and is working on a rigorous analysis under full quantum field theory. At the same time, Urban and colleagues suggest new experiments to test the connection. So it is reasonable to hope that c will at last be grounded in a more fundamental theory. And then – mystery solved? Well, that depends on your point of view. (3)

The speed of light is, of course, just one of several 'fundamental' or 'universal' physical constants. These are believed to apply to the entire universe and to remain fixed over time. The gravitational constant G, for example, defines the strength of gravity throughout the Universe. At small scales, Planck's constant h sets the size of quantum effects and the tiny charge on the electron e is the basic unit of electricity. The numerical values of these and other constants are known to excruciating precision. But all these quantities raise a host of unsettling questions. Are they truly constant? In what way are they 'fundamental'? Why do they have those particular values? What do they really tell us about the physical reality around us? Whether the 'constants' are really constant throughout the Universe is an ancient philosophical controversy. Aristotle believed that the Earth was differently constituted from the heavens. Copernicus held that our local piece of the Universe is just like any other part of it. Today, science follows the modern Copernican view, assuming that the laws of physics are the same everywhere in spacetime. But an assumption is all this is. It needs to be tested, especially for G and c, to make sure we are not misinterpreting what we observe in the distant universe. It was the Nobel Laureate Paul Dirac who raised the possibility that G might vary over time. In 1937, cosmological considerations led him to suggest that it decreases by about one part in 10 billion per year. Was he right? Probably not. Observations of astronomical bodies under gravity do not show this decrease, and so far there is no sign that G varies in space. Its measured value accurately describes planetary orbits and spacecraft trajectories throughout the solar system, and distant cosmic events, too. Radio astronomers confirmed that G as we know it correctly describes the behaviour of a pulsar (the rapidly rotating remnant of a supernova) 3,750 light years away. Similarly, there seems to be no credible evidence that c varies in space or time. (4)

So, let's assume that these constants really are constant. Are they fundamental? Are some more fundamental than others? What do we even mean by 'fundamental' in this context? One way to approach the issue would be to ask what is the smallest set of constants from which the others can be derived. Sets of two to 10 constants have been proposed, but one useful choice has been just three: h, c and G, collectively representing relativity and quantum theory. In 1899, Max Planck, who founded quantum physics, examined the relations among h, c and G and the three basic aspects or dimensions of physical reality: space, time, and mass. Every measured physical quantity is defined by its numerical value and its dimensions. We don't quote c simply as 300,000, but as 300,000 kilometres per second, or 186,000 miles per second, or 0.984 feet per nanosecond. The numbers and units are vastly different, but the dimensions are the same: length divided by time. In the same way, G and h have, respectively, dimensions of [length3/(mass x time2)] and [mass x length2/time]. From these relations, Planck derived 'natural' units, combinations of h, c and G that yield a Planck length, mass and time of 1.6 x 10-35 metres, 2.2 x 10-8 kilogrammes, and 5.4 x 10-44seconds. Among their admirable properties, these Planck units give insights into quantum gravity and the early Universe. But some constants involve no dimensions at all. These are so-called dimensionless constants – pure numbers, such as the ratio of the proton mass to the electron mass. That is simply the number 1836.2 (which is thought to be a little peculiar because we do not know why it is so large). According to the physicist Michael Duff of Imperial College London, only the dimensionless constants are really ‘fundamental’, because they are independent of any system of measurement. Dimensional constants, on the other hand, ‘are merely human constructs whose number and values differ from one choice of units to the next’. Perhaps the most intriguing of the dimensionless constants is the fine-structure constant α. It was first determined in 1916, when quantum theory was combined with relativity to account for details or ‘fine structure’ in the atomic spectrum of hydrogen. In the theory, α is the speed of the electron orbiting the hydrogen nucleus divided byc. It has the value 0.0072973525698, or almost exactly 1/137. Today, within quantum electrodynamics (the theory of how light and matter interact), α defines the strength of the electromagnetic force on an electron. This gives it a huge role. Along with gravity and the strong and weak nuclear forces, electromagnetism defines how the Universe works. But no one has yet explained the value 1/137, a number with no obvious antecedents or meaningful links. The Nobel Prize-winning physicist Richard Feynman wrote that α has been ‘a mystery ever since it was discovered… a magic number that comes to us with no understanding by man. You might say the “hand of God” wrote that number, and “we don’t know how He pushed his pencil”.’ Whether it was the ‘hand of God’ or some truly fundamental physical process that formed the constants, it is their apparent arbitrariness that drives physicists mad. Why these numbers? Couldn't they have been different? One way to deal with this disquieting sense of contingency is to confront it head-on. This path leads us to the philosophical idea that what we observe in the Universe must be compatible with the fact that we humans are here to observe it. A slightly different value for α would change the Universe; for instance by making it impossible for stellar processes to produce carbon, meaning that our own carbon-based life would not exist. In short, the reason we see the values that we see is that, if they were very different, we wouldn't be around to see them. QED. Such considerations have been used to limit α to between 1/170 and 1/80, since anything outside that range would rule out our own existence. (5)

But these arguments also leave open the possibility that there are other universes in which the constants are different. And though it might be the case that those universes are inhospitable to intelligent observers, it's still worth imagining what one would see if one were able to visit. For example, what if c were faster? Light seems pretty quick to us, because nothing is quicker. But it still creates significant delays over long distances. Space is so vast that aeons can pass before starlight reaches us. Since our spacecraft are much slower than light, this means that we might never be able to send them to the stars. On the plus side, the time lag turns telescopes into time machines, letting us see distant galaxies as they were billions of years ago. If c were, say, 10 times bigger, a lot of things would change. Earthly communications would improve. We'd cut the time lag for radio signals over big distances in space. NASA would gain better control over its unmanned spacecraft and planetary explorers. On the other hand, the higher speed would mess up our ability to peer back into the history of the Universe. Or imagine slow light, so sluggish that we could watch it slowly creep out of a lamp to fill a room. While it wouldn't be useful for much in everyday life, the saving grace is that our telescopes would carry us back to the Big Bang itself. (In a sense, 'slow light' has been achieved in the lab. In 1999, researchers brought laser light to the speed of a bicycle, and later to a dead stop, by passing it through a cloud of ultra-cold atoms.) These possibilities are entertaining to think about – and they might well be real in adjacent universes. But there's something very intriguing about how tightly constructed the laws of our own Universe appear to be. Leuchs points out that linking c to the quantum vacuum would show, remarkably, that quantum fluctuations are 'subtly embedded' in classical electromagnetism, even though electromagnetic theory preceded the discovery of the quantum realm by 35 years. The linkage would also be a shining example of how quantum effects influence the whole Universe. And if there are multiple universes, unfolding according to different laws, using different constants, this reasoning might well suffice to explain why we observe the particular regularities we find in our own world. Presumably the different parts of the multiverse would have to connect to one another in specific ways that follow their own laws – and presumably it would in turn be possible to imagine different ways for those universes to relate. Why should the multiverse work like this, and not that? Perhaps it isn't possible for the intellect to overcome a sense of the arbitrariness of things. We are close here to the old philosophical riddle, of why there is something rather than nothing. That's a mystery into which perhaps no light can penetrate. (6)

Adapted from Aeon

Exercise III.

Find paragraphs, dealing with the following: arena, arbitrariness, half-diameter, subsequent, empirically, indefiniteness, billiard, jitter, virtual, heavens

Exercise IV.

Fill in the gaps.

1. Instead of a big, blue **……..** on the wall of No 125, there's a tiny brass plate.
2. It seems to me that there is often a ……… between male and female opinion.
3. Nature was more precious because its beauty was often brief and ……...
4. The proton has an intrinsic angular **………** or spin, just like other particles.
5. Seeing time as the fourth **…………** made sense of Einstein's special relativity.
6. Scientists have long agreed on a general picture of what causes **………** emission.
7. First, the **………….** inducements greatly influence the time and response of behavior.
8. In some countries, a prohibition of **……..** is enshrined into the constitution.

9. Plato called this the Great Year, and other Greeks called it an **……..** or eon.
10. In fact, youth unemployment signals problems beyond the **………** of public opinion.

Exercise V .

Make up sentences of your own with the following word combinations: to come about, to get around, ensuing, to be off, on the face of it, to take time, to come to an end, to take the measurement, to put it another way, at rest

Exercise VI.

Determine whether the statements are true or false. Correct the false statements:

1. Light travels at around 300,000 km per minute.
2. If you visit the Paris Observatory on the right bank of the Seine, you'll see a plaque on its wall announcing that the speed of light was first measured there in 1676.
3. Ole Rømer, a Dane who was working as an assistant to the Italian astronomer Giovanni Domenico Cassini, was trying to account for certain discrepancies in eclipses of one of the moons of Earth.
4. Rømer and Cassini discussed the possibility that light has a finite speed (it had typically been thought to move instantaneously).
5. Eventually, following some rough calculations, Rømer concluded that light rays must take 10 or 11 minutes to cross a distance 'equal to the half-diameter of the terrestrial orbit'.

6. Rømer argued that if finite speed was the problem, and light really did take time to get around, the same delay ought to be visible in measurements of Jupiter’s other moons – and it wasn’t.
7. We have now fixed the speed of light in a vacuum at exactly 299,792.458 kilometres per second.
8. Quantum theory gave a first crucial insight 150 years ago.
9. The Scottish physicist James Clerk Maxwell showed that when electric and magnetic fields change in time, they interact to produce a travelling electromagnetic wave.
10. Maxwell calculated the speed of the wave from his equations and found it to be exactly the known speed of light.

<u>Exercise VII</u> .

Match the words to the definitions in the column on the right:

estimate	an area of interest or activity
to jitter	to be enough
momentum	to move or shake slightly in anuncontrolled way
universe	a strange and difficult question that has aclever and often funny answer
contigency	everything that exists, especially all physical matter, including all the stars, planets, galaxies, etc. in space
aeon	something that might possibly happen in the future, usually causing problems or making further arrangements necessary
adjacent	a guess of what a size, value, amount, etc might be

realm	the force or speed of an object inmotion, or the increase in the rate ofdevelopment of a process
suffice	a period of time that is so long that it cannot be measured
riddle	very near, next to, or touching

Exercise VIII.

Summarize the article “Light dawns”.

Part 2

Exercise I.

Identify the part of speech the words belong to:

discrepancy, antecedent, terrestrial, measurement, controversy, alternative , original, observation, electromagnetic, crucial

Exercise II .

Form nouns from the following words:

evanescent (2), typically (2), estimate (2), electric (2), interact (2), produce (2), special (2), move (2), know (2), connect (2)

Exercise III.

Find synonyms to the following words. Translate them into Russian: estimate (1), plaque (2), discrepancy (2), evanescent (2), quiver (2), momentum (3), dimension (5), antecedent (5), adjacent (6), aeon (6)

Exercise IV.

Find antonyms to the following words. Translate them into Russian:

faster (1), closer (1), certain (2), light (2), finite (2), rough (2), equal (2), visible (2), exactly (2), universal (2)

Exercise V.

Match the words to make word combinations:

second	way
fine-structured	particles
dead	fluctuation
alternative	Principle
empty	stop
elementary	thought
quantum	field
electric	system
solar	constant
uncertainty	space

2. Quantum common sense

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: reputation, mechanics, intuition, interest, physics, reality, normal, conceptions, objects, classical

Exercise II.

Make sure you know the following words and word combinations.

to confound, to defy, to laud, crucially, arbitrary, inextricably, to implore, to wedge, to evade, to languish

Quantum common sense

Despite its confounding reputation, quantum mechanics both guides and helps explain human intuition (1)

Qantum theory contradicts common sense. Everyone who has even a modest interest in physics quickly gets this message. The quantum view of reality, we're often told, is as a madhouse of particles that become waves (and vice versa), and that speak to one another through spooky messages that defy normal conceptions of time and space. We think the world is made from solid, discrete objects, things that have objective properties that we can all agree on; but in quantum mechanics the whole concept of classical objects with well-defined identities seems not to exist. Sounds ridiculous? The much-lauded physicist Richard Feynman thought so, yet he implored us to learn to live with it. ‘I hope you can accept Nature as She is – absurd,’ he said in 1985. Except that much of the popular picture is wrong. Quantum theory doesn’t actually say that particles can become waves or communicate in spooky ways, and it certainly does not say that classical objects don’t exist. Not only does it not deny the existence of classical objects, it gives a meaningful account of why they do exist. In some important respects, the modern formulation of the theory reveals why common sense looks the way it does. Our world, and our intuition, are quantum all the way up. Why, then, is it still so common to find talk of quantum mechanics defying logic and generally messing with reality? We might have to put some of the blame on the Danish physicist Niels Bohr. He was probably the deepest thinker about the meaning of quantum theory among its founding pioneers, and his intuitions were usually right. But during the 1920s and ’30s, Bohr drove a lasting wedge between the quantum and classical worlds. They operate according to quite different principles, he said, and we simply have to accept that. According to Bohr, what quantum mechanics tells us is not how the world is, but what we’ll find when we make measurements. The mathematical machinery of the theory gives us the probabilities of the various possible outcomes. When we make a measurement, we get just one of those possibilities, but there’s no telling which; nature’s selection is random. The quantum world is probabilistic, whereas the classical world (which is where all of our measurements happen) contains only unique outcomes. Why? That’s just how things are, Bohr answered, and it is fruitless to expect quantum mechanics to supply deeper answers. It tells us (with unflagging reliability) what to expect. What more do you want? Bohr’s

‘Copenhagen interpretation’ didn’t exactly declare a contradiction between classical and quantum physics, but it implied an incompatibility that Bohr patched over with a mantra of what he called ‘complementarity’. The classical and quantum worlds are complementary aspects of reality, he said: there’s common sense and there’s quantum sense, but you can’t have both – at least, not at the same time. The principle of complementarity seemed a deeply unsatisfying compromise to many physicists, since it not only evaded difficult questions about the nature of reality but essentially forbade them. Still, complementarity had at least the virtue of pinpointing where the problems lay: in understanding what we mean by measurement. It is through measurement that objects become things rather than possibilities – and furthermore, they become things with definite states, positions, velocities and other properties. In other words, that’s how the counterintuitive quantum world gives way to common-sense experience. What we needed to unite the quantum and classical views, then, was a proper theory of measurement. There things languished for a long time. (2)

Now we have that theory. Not a complete one, mind you, and the partial version still doesn’t make the apparent strangeness of quantum rules go away. But it does enable us to see why those rules lead to the world we experience; it allows us to move past the confounding either/or choice of Bohr’s complementarity. The boundary between quantum and classical turns out not to be a chasm after all, but a sensible, traceable path. It’s a strange idea that measurement needs explaining at all. Usually what we mean by a measurement seems so trivial that we don’t even ask the question. A ball has a position, or a speed, or a mass. I can measure those things, and the things I measure are the properties of the ball. What more is there to say? But in the quantum world things aren’t so obvious. There, the position of a particle is nothing more than a whole set of possible positions until the moment when it is observed. The same holds true for any other aspect of the particle. How does the multitude of potential properties in a quantum object turn into one specific reading on a measuring device? What is it about the object that caused the device to point to that precise answer? The modern answer is surprising: the act of measurement doesn’t entail a collapse of quantum-ness and a shift to classical-ness after all. Quantum objects have a wave nature – which is to say, the theory tells us that they can be described as if they were waves, albeit waves of a peculiar sort. The waves do not move through any physical substance, as do waves in air or water, but are encoded in a purely mathematical object called a wave function that can be converted to probabilities of values of observable quantities. As a result, quantum particles (such as photons of light, electrons, atoms, or even entire molecules) can exhibit interference, a classical property of waves in which two peaks reinforce each other when they overlap, whereas when a peak coincides with a trough the two can cancel each other out. It’s hard to talk about this phenomenon without giving the impression that the particles themselves are somehow wavy, and the unfortunate expression ‘wave-particle duality’ only compounds the confusion. But all we’re really seeing here is a feature of the particles’ wave functions, for want of a better term. Asking if these quantum objects really are particles or waves misses the point, because both of those are classical concepts. The reason we ask anyway is that we're trying instinctively to recover some common-sense picture of the quantum world. But what we call 'common sense' is a feature of the classical world, and we can't expect to use it for quantum things. Quantum effects such as interference rely on the wave functions of different entities being coordinated (the technical term is coherent) with one another. Coherence is what permits the quantum property of superposition, in which particles are said to be in two or more states at once. Again, they're not really in two states at once – we don't know how best to describe what they really are in a classical sense. But if the wave functions of those states are coherent, then both states remain possible outcomes of a measurement. If their wave functions are not coherent, two states cannot interfere, nor maintain a superposition. The process called decoherence therefore destroys these fundamentally quantum properties, and the states behave more like distinct classical systems. Macroscopic objects don't display quantum interference or exist as superpositions because they can't be described by coherent wave functions. This – and not sheer size per se – is the fundamental dividing line between what we think of as quantum versus classical (familiar) behaviour. Quantum coherence is essentially what defines 'quantum-ness'. (3)

What, though, causes decoherence? This arises because of a long-neglected aspect of quantum entities: their environment. The way a quantum system behaves and evolves can depend crucially on the fact that it doesn't exist in isolation. There's no obvious reason why decoherence couldn't have been understood by Bohr and his peers in the early days of quantum mechanics, because it involves nothing but the basic principles of quantum theory. The reason it was neglected might have been largely because that's what usually happens in science. Researchers figure that they can focus in on the system they're interested in, and either ignore its surroundings totally or relegate them to a minor background perturbation. Usually that works fine. But not if we want to observe anything about the quantum world. The foundations of decoherence theory were laid in the 1970s by the German physicist H Dieter Zeh. Even then it was largely ignored until two papers on the 'decoherence programme' the following decade, by Wojciech Zurek at the Los Alamos National Laboratory in New Mexico, brought it to a wide audience. Zurek displays a laconic calm in the face of the mind-boggling aspects of quantum mechanics that he has uncovered. Zurek has become one of the key architects and advocates of decoherence theory, helping to establish it as the central concept connecting the quantum and classical worlds. This connection comes from the fact that quantum coherence is contagious. If one quantum object interacts with another, they become linked into a composite superposition: in some sense, they become a single system. This is, in fact, the only thing that can happen in such an interaction, according to quantum mechanics. The two objects are then said to be entangled. It might sound spooky, but this is merely what happens when a quantum system interacts with its environment – as a photon of light or an air molecule bounces off it, say. As a result, coherence spreads into the environment. In theory, there is no end to this process. An entangled air molecule hits another, and the second molecule gets drawn into the entangled state. Meanwhile, other particles hit the initial quantum system, too. As time passes, the system becomes more and more entangled with its environment, which means that it can't be broken down into separate entities any more. This spreading of entanglement is the thing that destroys the manifestation of coherence in the original quantum system. Because superposition becomes a shared property of the system and its environment, we can't any longer see the superposition just by looking at the little part of that shared state corresponding to the original system. We can't see the wood for the trees, you might say. Decoherence is not actually a loss of superposition and coherence, but rather a loss of our ability to detect these things in the original system. Only by looking closely at the states of all the entangled particles can we deduce that they're in a superposition. And how can we possibly hope to do that – to monitor every photon that bounces off the original system, every air molecule that collided with it and then subsequently with others? The pieces of the puzzle have been scattered so widely that they are lost, for all practical purposes, even though in principle they are still out there, and remain so (as far as quantum mechanics tells us) indefinitely. That's the essence of what decoherence is: a loss of (personally) meaningful coherence. It is a gradual and real process that occurs at a particular rate. The issue is not really about whether probing physically disturbs what is probed (although that can happen). It is the gathering of information that alters the picture. Through decoherence, the Universe retains selected highlights of the quantum world, and those highlights have exactly the features that we have learnt to expect from the classical world. We come along and sweep up that information – and in the process we destroy it, one copy at a time. (4)

Decoherence doesn’t completely neutralise the puzzle of quantum mechanics. Most importantly, it does not explain the issue of uniqueness: why, out of the possible outcomes of a measurement that survive decoherence, we see only one of them. All the same, thanks to the theory of decoherence, there’s no longer any need for Bohr’s arbitrary division of the world into the microscopic, where quantum mechanics rules, and macroscopic, which is necessarily classical. Now we can see not only that they are a continuum, but also that classical physics is just a special case of quantum physics. This quantum theory of measurement is a reversal of the usual way that science works. We normally take our human common sense and experience for granted, and work back from it to deduce more fundamental physical behaviours. Sure, what we discover that way might sometimes seem a long way from common sense – Higgs bosons, black holes, etc. But we typically get to those points by taking it for granted that there is an uncomplicated relationship between what we measure and what is there. Decoherence theory doesn’t take that common-sense view of measurement for granted. It starts by accepting that the world is fundamentally governed by quantum rules, which seem at face value to run deeply counter to experience, and then it works upwards to see if it can recover common sense. Remarkably, it can. That is why the quantum theory of measurement can be thought of as nothing less than a ‘theory of common sense’. Decoherence theory explains where common sense comes from – namely, out of principles that seem very far from common-sensical. The challenge is then on all of us to reconcile our instinctive common sense with its quantum origins. But we no longer have to regard the two as being in conflict, since they are not only consistent but inextricably linked. We can seek solace in the knowledge that the conflict between classical and quantum is not in the physics. It's just in our minds. (5)

Adapted from Aeon.

Exercise III.

Find paragraphs, dealing with the following:

albeit, mind-boggling, chasm, sheer, madhouse, pioneers, fruitless, mantra, compromise, inextricably

Exercise IV.

Fill in the gaps.

1. As we age, we need to get more nutritional **………** out of the calories we consume.
2. In this case, the **…………** -state material was an electron within a diamond crystal.
3. A spokesman for Anthony's attorney said calling Anthony a suspect is **…………**.
4. They directly measured the **………..** of the exoplanet as it orbits its home star.
5. A companion **………..** at Arte Italia provides explanatory panels, video and books.
6. The extra hour is intended to develop and **………..** fundamental literacy skills.

7. On this East Bay excursion, a tunnel transports visitors to two **………** worlds.
8. The tactile experience of reading is **…………** important to my reading pleasure.
9. But Forman's plan was enacted, and **…………** five other states adopted plans.
10. Under the right conditions, bacteria can degrade spilled oil **…………..** quickly.

<u>Exercise V</u> .

Make up sentences of your own with the following word combinations: way up, to sweep up, to seek solace, to take it for granted, in some sense, to put some of the blame on, to bounce off something, far from common-sensical, at a time, to collide with

<u>Exercise VI</u>.

Determine whether the statements are true or false. Correct the false statements:

1. Qantum theory does not contradict common sense.
2. We think the world is made from solid, discrete objects, things that have objective properties that we can all agree on; but in quantum mechanics the whole concept of classical objects with well-defined identities seems not to exist.
3. But during the 1920s and ’30s, Bohr drove a lasting wedge between the quantum and classical worlds.
4. According to Bohr, what quantum mechanics tells us is not how the world is, but what we’ll find when we make measurements.

5. The quantum world is probabilistic, whereas the classical world (which is where all of our measurements happen) contains only unique outcomes.
6. Bohr’s ‘Copenhagen interpretation’ exactly declared a contradiction between classical and quantum physics.
7. The classical and quantum worlds are complementary aspects of reality, he said: there’s common sense and there’s quantum sense, and you can have both –at the same time.
8. The principle of complementarity seemed a deeply unsatisfying compromise to many physicists, since it not only evaded difficult questions about the nature of reality but essentially forbade them.
9. Still, complementarity had at least the virtue of pinpointing where the problems lay: in understanding what we mean by measurement.
10. It is through measurement that objects become possibilities rather than things.

<u>Exercise VII</u> .

Match the words to the definitions in the column on the right:

solid	to involve or make something necessary
velocity	to show something publicly
laconic	to make something <u>stronger</u>
to exhibit	involved with something or someone in a way that makes itdifficult to escape
reinforce	the best, most important, or mostinteresting part
retain	using very few words to express what youmean
highlight	not liquid or gas
to entail	the speed at which an object is travelling
entangled	to keep or continue to have something

reconcile	to find a way in which two situations orbeliefs that are opposed to each other canagree and exist together

Exercise VIII.

Summarize the article “Quantum Common Sense”.

Part 2

Exercise I.

Identify the part of speech the words belong to.

entity, distinct, trivial, discrete, incompatibility, complimentarity, consistent, intuition, meaningful, formulation

Exercise II .

Form adjectives from the following words: value, subsequently, sense (1), quickly (2), reality (2), hope (2), communicate (2), possibility (2), physics (2), decoherence (3), indefinitely (4), remarkably (5)

Exercise III.

Find synonyms to the following words. Translate them into Russian: intuition (2), logic (2), probably (2), classical (2), measurement (2), probability (2), selection (2), random(2), unique (2), reinforce (3)

Exercise IV.

Find antonyms to the following words. Translate them into Russian: existence (2), important (2), reality (2), blame (2), deep (2), right (2), different (2), possible (2), coherent (3), reconcile (6)

Exercise V.

Match the words to make word combinations:

wave	substance
face	theory
common	pioneers
quantum	holes
modest	function
deepest	answer
physical	value
black	thinker
founding	sense
precise	interest

3. How Much More Can We Learn About the Universe?

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: fundamental, moment, indication, demonstrate, remarkable, history, principle, interval, special , experimental

Exercise II

Make sure you know the following words and word combinations.
to expand, roadblock, unsubstantiated, consistent, offset, to endure, to decouple, traction, putative

How Much More Can We Learn About the Universe?

These are the few limits on our ability to know. (1)

As a cosmologist, some of the questions I hear most frequently after a lecture include: What lies beyond our universe? What is our universe expanding into? Will our universe expand forever? These are natural questions to ask. But there is an even deeper question at play here. Fundamentally what we really want to know is: Is there a boundary to our knowledge? Are there fundamental limits to science? The answer, of course, is that we don't know in advance. We won't know if there is a limit to knowledge unless we try to get past it. At the moment, we have no sign of one. We may be facing roadblocks, but those give every indication of being temporary. Some people say to me: “We will never know how the universe began.” “We can never know what happened before the Big Bang.” These statements demonstrate a remarkable conceit, by suggesting we can know in advance the locus of all those things that we cannot know. This is not only unsubstantiated, but the history of science so far has demonstrated no such limits. And in my own field, cosmology, our knowledge has increased in ways that no one foresaw even 50 years ago. This is not to say that nature doesn’t impose limits on what we can observe and how we can observe it. For example, the Heisenberg uncertainty principle constrains what we can know about the motion of a particle at any time, and the speed of light restricts how far we can see or travel in a given interval. But these limits merely tell us what we cannot observe, not what we cannot eventually learn. The uncertainty principle hasn’t gotten in the way of learning the rules of quantum mechanics, understanding the behavior of atoms, or discovering that so-called virtual particles, which we can never see directly, nevertheless exist. (2)

The observation that the universe is expanding does imply a beginning, because if we extrapolate backward, then at some point in the distant past, everything in our observable universe was co-located at a single point. At that instant, which now goes by the name of the Big Bang, the laws of physics as we know them break down, because general relativity, which describes gravity, cannot be successfully integrated with quantum mechanics, which describes physics on microscopic length scales. But most scientists do not view this as a fundamental boundary to knowledge, because we expect that general relativity will have to be modified as part of a consistent quantum theory. String theory is one of the major ongoing efforts to do so. Given such a theory, we might be able to answer the question of what, if anything, came before the Big Bang. The simplest possible answer is perhaps also the least satisfying. Both special and general relativity tie together space and time into a single entity: spacetime. If space was created in the Big Bang, then perhaps time was as well. In that case, there was no "before." It simply wouldn't be a good question. This is not the only possible answer, though, and we will need to await a quantum theory of gravity and its experimental confirmation before we will have any confidence in our reply. (3)

Then there is the question of whether we can know what lies beyond our own universe, spatially. What are the boundaries of our universe? Again, we can hazard a guess. If our spacetime arose spontaneously—which seems the most likely possibility—then it probably has zero total energy: The energy represented by matter is exactly offset by the energy represented by gravitational fields. Put simply, something can arise from nothing if the something amounts to nothing. Right now, the only universe that we can verify has zero total energy is a closed universe. Such a universe is finite yet unbounded. Just like you can move around the surface of a sphere forever without encountering any boundaries, the same may be true of our universe. If we look far enough in one direction, we would see the back of our heads. In practice, we cannot do that, probably because our visible universe is only part of a much larger volume. The reason has to do with something called inflation. Most universes that arise spontaneously with microscopic size will re-collapse in a microscopic time, rather than endure for billions of years. But, in some, empty space will be endowed with energy, and that will cause the universe to expand exponentially fast, at least for a brief period. We think that such a period of inflation occurred during the earliest moments of our Big Bang expansion and prevented the universe from re-collapsing immediately. In the process, the universe puffed up in size to become so great in extent that, for all intents and purposes, it would now appear flat and infinite—like a cornfield in Kansas that looks infinite despite being located on the huge sphere we call Earth. This is why we don't see the backs of our heads when we look up in space, even though our universe may be closed on its largest scales. In principle, though, we could see the whole thing if we waited long enough, as long as inflation hadn't resumed in our visible universe, and is not occurring elsewhere in regions of space we cannot observe. As for the possibility that regions we cannot yet observe, or may never observe, may be inflating, in fact our current theories suggest that this is the most likely possibility. If we consider the phrase "our universe" to refer to that region of space with which we once could have communicated or with which we one day may communicate, then inflation generally creates other universes beyond ours. Inflation may have been brief within our volume of space, but the rest of space expands exponentially forever, with isolated regions like ours occasionally decoupling from the expansion, just as isolated ice patches can form on the surface of fast-moving water when the temperature is below freezing. Each such universe had a beginning, pegged to the time when inflation ended within its spatial volume. In this case, the beginning of our universe may not have been the beginning of time itself—further reason to doubt whether the Big Bang represents an ultimate limit to our knowledge. (4)

Depending on the processes that cause each universe to decouple from the background space, the laws of physics might be different in each one. We have come to call this collection of possible universes a "multiverse." The idea of a multiverse has gained traction in the scientific community not only because it is motivated by phenomena like inflation, but also because the possibility of many different universes, each with its own laws of physics, might explain various seemingly inexplicable fundamental parameters of our universe. Those parameters are simply the values that randomly arose when our universe was born. If other universes are out there, they are separated from ours by huge distances and recede at super-light relative velocities, so we can never detect them directly. Is the multiverse then just metaphysics? Does verifying the possible existence of a multiverse thus represent a fundamental boundary to our knowledge? The answer is: not necessarily. Although we may never see another universe directly, we can still test the theory that may have produced it empirically—for example, by observing that inflation would produce. This would allow us in principle to test the detailed nature of the inflationary process that resulted in our universe. They come from the earliest moments of the Big Bang, during the putative period of inflation. If we can detect them directly—as we might be able to do in a variety of experiments that are now looking for the signature they would leave in the cosmic microwave background radiation left over from the Big Bang—we can probe the physics of inflation and then determine whether eternal inflation is a consequence of this physics. Thus, indirectly, we could test whether other universes must exist, even if we cannot detect them directly. In short, we have discovered that even the very deepest metaphysical questions—which previously we might have imagined would never be empirically addressable, including the possible existence of other universes—may in fact be accessible, if we are clever enough. No limits to what we may learn from the application of reason combined with experimental observation are yet known. (5)

A universe without limits is appealing and motivates us to continue searching. But can we be confident there will be no limits to our knowledge, ever? Not quite. Inflation does place a fundamental limit on knowledge—specifically, knowledge of the past. It essentially resets the universe, destroying potentially all the information about the dynamical processes that preceded it. The rapid expansion of space during inflation severely dilutes the contents of any region. So it may have wiped out traces of, for example, , a type of particle that theory suggests the very early universe produced in profusion. That was one of the original virtues of inflation: It reconciled the fact we have never seen such particles with predictions of their production. But in getting rid of a discrepancy, inflation erased aspects of our past. Worse, the erasure may not be over. We are apparently living in another period of inflation right now. Measurements of the recession of distant galaxies indicates that the expansion of our universe is currently speeding up, not slowing down, as it would be if the dominant gravitational energy resided in matter or radiation, and not in empty space. We currently have no understanding of the origin of this energy. Each of the potential explanations suggests fundamental limits to the progress of knowledge and even to our very existence. The energy of empty space could suddenly disappear if the universe undergoes some kind of phase transition, a cosmic version of steam condensing into liquid water. If that were to happen, the nature of fundamental forces might change, and all the structures we see in the universe, from atoms on up, might become unstable or disappear. We would disappear along with everything else. But even if the expansion continues, the future is still rather dismal. Within about 2 trillion years—which may seem like a long time on human scales, but is not so long on cosmic scales—the rest of the universe will disappear from our view. Any observers who evolve on planets around stars in this distant future will imagine that they live on a single galaxy surrounded by an eternal empty space, with no signs of acceleration or even any evidence of an earlier Big Bang. Just as we have lost sight of monopoles, they will be blind to the history that we readily see. (To be sure, they may have access to observable phenomenon we do not yet have access to, so we shouldn't feel too superior.) Either way, we should enjoy our brief moment in the sun and learn what we can, while we can. Work harder, graduate students! (6)

Adapted from Nautilus.

Exercise III.

Find paragraphs, dealing with the following: temporary, locus, unsubstantiated, foresee, interval, merely, virtual, extrapolate, instant, await

Exercise IV.

Fill in the gaps.

1. It is clear from these translations that Krasznahorkai is a ……. novelist.
2. As before, this only proves that the magnetization is zero at any …….. volume.
3. The wonders of the atom, or more properly the nucleus, were felt to be ………...
4. It has been suggested that one cannot………….. Ai's art from its Chinese context.
5. So dark energy is a form of energy that does not ……. as the universe expands.
6. If no match turns up in the database, the device is supposed to ……….. the print.
7. Patients hospitalized with acute heart failure commonly have a ……… prognosis.
8. The proposals are ………… with the city's growth management plan, Simon said.
9. They can encourage insect damage, weaken the foundation or create a fire ………..
10. One ………… King County is the economic center is that all roads lead to Seattle.

Exercise V .

Make up sentences of your own with the following word combinations: in advance (1), at any time (1), in the distant past (2), to tie together (2), to arise spontaneously (3), to put simply(3), to arise from nothing (3), in practice (3), to puff up(3), for all intents and purposes (3).

Exercise VI.

Determine whether the statements are true or false. Correct the false statements:

1. The Heisenberg uncertainty principle restricts how far we can see or travel in a given interval.
2. The uncertainty principle hasn't gotten in the way of learning the rules of quantum mechanics, understanding the behavior of atoms, or discovering that so-called virtual particles, which we can never see directly, nevertheless exist.
3. The observation that the universe is expanding does imply a beginning, because if we extrapolate backward, then at some point in the distant past, everything in our observable universe was co-located at a single point.
4. At that instant, which now goes by the name of the Big Bang, the laws of physics as we know them break down, because general relativity, which describes gravity, can be successfully integrated with quantum mechanics, which describes physics on microscopic length scales.
5. Both special and general relativity tie together space and time into a single entity: spacetime.
6. If space was created in the Big Bang, then perhaps time was as well.
7. If our spacetime arose spontaneously—which seems the most unlikely possibility—then it probably has zero total energy: The energy represented by matter is exactly offset by the energy represented by gravitational fields.
8. Right now, the only universe that we can verify has zero total energy is a closed universe.
9. Our universe is infinite.
10. Measurements of the recession of distant galaxies indicates that the expansion of our universe is currently speeding up, not

slowing down, as it would be if the dominant gravitational energy resided in matter or radiation, and in empty space.

Exercise VII .

Match the words to the definitions in the column on the right:

finite	with the power of a magnet
hazard	to search into or examine something
unbounded	to change the details of something
to probe	to risk doing something, especially making a guess, suggestion, etc.
to reset	sad and without hope
to dilute	to stay in a place
magnetic	having a limit or end
to erase	to lessen the strength of (something)
to reside	to have no limits
dismal	to cause a feeling, memory, or period oftime to be completely forgotten

Exercise VIII.

Summarize the article "How Much More Can We Learn About the Universe?"

Part 2

Exercise I.

Identify the part of speech the words belong to.

remarkable, accessible, reason, essentially, profusion, signature, extent, discrepancy, cosmologist, boundary

Exercise II .

Form verbs from the following words: consistent (3), confirmation (3), inflation (4), relative (5), radiation (5), addressable (5), accessible (5), application (5), erasure (6), recession (6)

Exercise III.

Find synonyms to the following words. Translate them into Russian: frequently (1), fundamentally (2), statement (2), demonstrate (2), field (2), observe (2), motion (2), restrict (2), rule (3), dilute (7)

Exercise IV .

Find antonyms to the following words. Translate them into Russian: ability (1), after (2), natural (2), increase (2), uncertainty (2), directly (2), distant (3), general (3), integrate (2), unbounded (4)

Exercise V.

Match the words to make word combinations:

distant	community
natural	student
gravitational	particles
graduate	period
scientific	water
magnetic	questions
Big	waves
virtual	monopoles
brief	Bang
fast-moving	galaxies

4. Minding matter

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following words: materialist, position, metaphysical, debates, brilliant, images, test, subjects, mysterious.

Exercise II.

Make sure you know the following words and word combinations.

redoubt, attribute, calculus, profound, to imply, baggage, burst, to lurk, to espouse, steep

Minding matter

The closer you look, the more the materialist position in physics appears to rest on shaky metaphysical ground (1)

Materialism holds the high ground these days in debates over that most ultimate of scientific questions: the nature of consciousness. When tackling the problem of mind and brain, many prominent researchers advocate for a universe fully reducible to matter. ‘Of course you are nothing but the activity of your neurons,’ they proclaim. That position seems reasonable and sober in light of neuroscience’s advances, with brilliant images of brains lighting up like Christmas trees while test subjects eat apples, watch movies or dream. And aren’t all the underlying physical laws already known? There is, however, a significant weakness hiding in the imposing-looking materialist redoubt. It is as simple as it is undeniable: after more than a century of profound explorations into the subatomic world, our best theory for how matter behaves still tells us very little about what matter is. Materialists appeal to physics to explain the mind, but in modern physics the particles that make up a brain remain, in many ways, as mysterious as consciousness itself. When I was a young physics student I once asked a professor: ‘What’s an electron?’ His answer stunned me. ‘An electron,’ he said, ‘is that to which we attribute the properties of the electron.’ That vague, circular response was a long way from the dream that drove me into physics, a dream of theories that perfectly described reality. Like almost every student over the past 100 years, I was shocked by quantum mechanics, the physics of the micro-world. In place of a clear vision of little bits of matter that explain all the big things around us, quantum physics gives us a powerful yet seemly paradoxical calculus. With its emphasis on probability waves, essential uncertainties and experimenters disturbing the reality they seek to measure, quantum mechanics made imagining the stuff of the world as classical bits of matter all but impossible. Like most physicists, I learned how to ignore the weirdness of quantum physics. ‘Shut up and calculate!’ works fine if you are trying to get 100 per cent on your Advanced Quantum Theory homework or building a laser. But behind quantum mechanics’ unequaled calculational precision lie profound, stubbornly persistent questions about what those quantum rules imply about the nature of reality – including our place in it. (2)

Those questions are well-known in the physics community, but perhaps our habit of shutting up has been a little too successful. In other fields materialism still appears to be the most sensible way of dealing with the world and, most of all, with the mind. Molecular biologists, geneticists, and many other types of researchers – as well as the nonscientist public – have been similarly drawn to materialism's seeming finality. But this conviction is out of step with what we physicists know about the material world – or rather, what we don't know. Albert Einstein and Max Planck introduced the idea of the quantum at the beginning of the 20th century, sweeping away the old classical view of reality. We have never managed to come up with a definitive new reality to take its place. The interpretation of quantum physics remains as up for grabs as ever. As a mathematical description of solar cells and digital circuits, quantum mechanics works just fine. But if one wants to apply the materialist position to a concept as subtle and profound as consciousness, something more must clearly be asked for. The closer you look, the more it appears that the materialist position is not the safe harbor of metaphysical sobriety that many desire. For physicists, the ambiguity over matter boils down to what we call the measurement problem, and its relationship to an entity known as the wave function. Back in the good old days of Newtonian physics, the behaviour of particles was determined by a straightforward mathematical law that reads F = ma. You applied a force F to a particle of mass m, and the particle moved with acceleration a. It was easy to picture this in your head. The equation F = ma gave you two things that matter most to the Newtonian picture of the world: a particle's location and its velocity. This is what physicists call a particle's state. Newton's laws gave you the particle's state for any time and to any precision you need. If the state of every particle is described by such a simple equation, and if large systems are just big combinations of particles, then the whole world should behave in a fully predictable way. Many materialists still carry the baggage of that old classical picture. It's why physics is still widely regarded as the ultimate source of answers to questions about the world, both outside and inside our heads. In Isaac Newton's physics, position and velocity were indeed clearly defined and clearly imagined properties of a particle. Measurements of the particle's state changed nothing in principle. The equation F = ma was true whether you were looking at the particle or not. All of that fell apart as scientists began probing at the scale of atoms early last century. In a burst of creativity, physicists devised a new set of rules known as quantum mechanics. A critical piece of the new physics was embodied in Schrödinger's equation. Like Newton's F = ma, the Schrödinger equation represents mathematical machinery for doing physics; it describes how the state of a particle is changing. But to account for all the new phenomena physicists were finding (ones Newton knew nothing about), the Austrian physicist Erwin Schrödinger had to formulate a very different kind of equation. When calculations are done with the Schrödinger equation, what's left is not the Newtonian state of exact position and velocity. Instead, you get what is called the wave function (physicists refer to it as psi after the Greek symbol used to denote it). Unlike the Newtonian state, which can be clearly imagined in a commonsense way, the wave function does not give you a specific measurement of location and velocity for a particle; it gives you only probabilities at the root level of reality. Psi appears to tell you that, at any moment, the particle has many positions and many velocities. In effect, the bits of matter from Newtonian physics are smeared out into sets of potentials or possibilities. It’s not just position and velocity that get smeared out. The wave function treats all properties of the particle (electric charge, energy, spin, etc) the same way. They all become probabilities holding many possible values at the same time. Taken at face value, it’s as if the particle doesn’t have definite properties at all. This is what the German physicist Werner Heisenberg, one of the founders of quantum mechanics, meant when he advised people not to think of atoms as ‘things’. Even at this basic level, the quantum perspective adds a lot of blur to any materialist convictions of what the world is built from. (3)

Then things get weirder still. According to the standard way of treating the quantum calculus, the act of making a measurement on the particle kills off all pieces of the wave function, except the one your instruments register. The wave function is said to collapse as all the potential positions or velocities vanish in the act of measurement. It’s like the Schrödinger equation, which does such a great job of describing the smeared-out particle before the measurement is made, suddenly gets a pink slip. You can see how this throws a monkey wrench into a simple, physics-based view of an objective materialist world. How can there be one mathematical rule for the external objective world before a measurement is made, and another that jumps in after the measurement occurs? For a hundred years now, physicists and philosophers have been beating the crap out of each other (and themselves) trying to figure out how to interpret the wave function and its associated measurement problem. What exactly is quantum mechanics telling us about the world? What does the wave function describe? What really happens when a measurement occurs? Above all,what is matter? There are today no answers to these questions. There is not even a consensus about what the answers should look like. Rather, there are multiple interpretations of quantum theory, each of which corresponds to a very different way of regarding matter and everything made of it – which, of course, means everything. The earliest interpretation to gain force, the Copenhagen interpretation, is associated with Danish physicist Niels Bohr and other founders of quantum theory. In their view, it was meaningless to speak of the properties of atoms in-and-of-themselves. Quantum mechanics was a theory that spoke only to our knowledge of the world. Not all researchers were so willing to give up on the ideal of objective access to a perfectly objective world, however. Some pinned their hopes on the discovery of hidden variables – a set of deterministic rules lurking beneath the probabilities of quantum mechanics. Others took a more extreme view. In the many-worlds interpretation espoused by the American physicist Hugh Everett, the authority of the wave function and its governing was taken as absolute. Measurements didn't suspend the equation or collapse the wave function, they merely made the Universe split off into many (perhaps infinite) parallel versions of itself. Thus, for every experimentalist who measures an electron over here, a parallel universe is created in which her parallel copy finds the electron over there.The many-worlds Interpretation is one that many materialists favor, but it comes with a steep price. Here is an even more important point: as yet there is no way to experimentally distinguish between these widely varying interpretations. Which one you choose is mainly a matter of philosophical temperament. On one side there are those who want the wave function to describe the objective world 'out there'. On the other side, there are those who see the wave function as a description of our knowledge and its limits. Right now, there is almost no way to settle the dispute scientifically. This arbitrariness of deciding which interpretation to hold completely undermines the strict materialist position. The real problem is that, in each case, proponents are free to single out one interpretation over others because … well … they like it. Everyone, on all sides, is in the same boat. There can be no appeal to the authority of 'what quantum mechanics says', because quantum mechanics doesn't say much of anything with regard to its own interpretation. Each interpretation of quantum mechanics has its own philosophical and scientific advantages, but they all come with their own price. One way or another, they force adherents to take a giant step away from the vision of little bits of matter, that was possible with the Newtonian world view. (4)

The attraction of the many-worlds interpretation, for instance, is its ability to keep the reality in the mathematical physics. In this view, yes, the wave function is real and, yes, it describes a world of matter that obeys mathematical rules, whether someone is watching or not. The price you pay for this position is an infinite number of parallel universes that are infinitely splitting off into an infinity of other parallel universes that then split off into… well, you get the picture. A particularly cogent new theory, called Quantum Bayesianism or QBism, raises this perspective to a higher level of specificity by taking the probabilities in quantum mechanics at face value. According to Fuchs, the leading proponent of QBism, the irreducible probabilities in quantum mechanics tell us that it's really a theory about making bets on the world's behaviour (via our measurements) and then updating our knowledge after those measurements are done. QBism attributes the muddle at the foundations of quantum mechanics to our unacknowledged removal of the scientist from the science. Given these difficulties, one must ask why certain weird alternatives suggested by quantum interpretations are widely preferred over others within the research community. Why does the infinity of parallel universes in the many-worlds interpretation get associated with the sober, hard-nosed position, while including the perceiving subject gets condemned as crossing over to the shores of anti-science at best, or mysticism at worst? When pressed on this issue, though, we physicists are often left looking at our feet, smiling sheepishly and mumbling something about ‘it’s complicated’. We know that matter remains mysterious. (5)

Exercise III.

Find paragraphs, dealing with the following: proclaim, movies, undeniable, appeal, attribute, vague, paradoxical, weirdness, community, molecular

Exercise IV.

Fill in the gaps.

1. According to Mangen, perception and sensorimotor now play a more ………….. role.
2. The article focuses on two simulation tools needed for …….. force microscopes.
3. The collection began with a fantastic ……… mirrored ball by Olafur Eliasson.

4. While Burke wasn't as famous as others in his field, his influence was …………
5. This particular one spanned 50 times the diameter of our planet before it …………….
6. Let's look at the issue strictly from a scientific and ………. perspective.
7. The idea that all or ……… particles were created all at once is unrealistic.
8. What if similar tensions are going ……………. between me and my colleagues?
9. Scientists ………… the slip to natural variation and an unusually cold winter.
10. So students that have taken ………. in high school are in a very good position.

Exercise V .

Make up sentences of your own with the following word combinations: up for grabs, common sense, to smear out, to take at face value, as yet, to get condemned, at best, at worst, to come with their own price, to take a giant step away from

Exercise VI.

Determine whether the statements are true or false. Correct the false statements:

1. Materialists appeal to medicine to explain the mind.
2. In modern physics the particles that make up a brain remain, in many ways, as mysterious as consciousness itself.
3. Albert Einstein and Max Planck introduced the idea of the quantum at the beginning of the 20th century, sweeping away the old classical view of reality.

4. Back in the good old days of Newtonian physics, the behaviour of particles was determined by a straightforward mathematical law that reads F = ma.
5. The equation F = ma gave you two things that matter most to the Newtonian picture of the world: a particle’s location and its velocity.
6. Newton’s laws gave you the particle’s state for any time and to any precision you need.
7. If the state of every particle is described by such a simple equation, and if large systems are just big combinations of particles, then the whole world should behave in a fully unpredictable way.
8. In Isaac Schrödinger’s physics, position and velocity were indeed clearly defined and clearly imagined properties of a particle.
9. In a burst of creativity, physicists devised a new set of rules known as quantum mechanics.
10. Like the Newtonian state, which can be clearly imagined in a commonsense way, the wave function gives you a specific measurement of location and velocity for a particle.

Exercise VII .

Match the words to the definitions in the column on the right:

hard-nosed	not generally recognized, accepted, or admitted
cogent	practical and determined
infinite	the quality of being exact
irreducible	a statement that two amounts, or two symbols or mathematical of symbols representing an amount, are equal
muddle	a person who strongly supports a particular person, principle, or set of ideas

unacknowledged	someone who believes that only physical matter exists and the spiritual world does not
equation	without limits; extremely large or great
precision	clearly expressed and persuades people to believe it.
materialist	a messy and confused state

Exercise VIII .

Summarize the article "Minding matter."

Part 2

Exercise I.

Identify the part of speech the words belong to:

prominent, atomic, circular, conviction, entity, velocity, arbitrariness, sobriety , physicist , ambiguity

Exercise II .

Form adverbs from the following words:

reasonable (2), brilliant (2), significant (2), mysterious (2), clear (2), powerful (2), essential (2), persistent (2), ultimate (3), successful (4)

Exercise III.

Find synonyms to the following words. Translate them into Russian: debate (2), image (2), circular (2), vision (2), response (2), calculus (2), emphasis (2), ignore (2), precision (3), profound (3)

Exercise IV.

Find antonyms to the following words. Translate them into Russian: fully (1), weakness (2), materialism (2), simple (2), subatomic (2), consciousness (2), reality (2), micro (2), unequaled (2), sensible (2)

Exercise V.

Match the words to make word combinations:

safe	position
digital	cells
Schrödinger	public
subatomic	wrench
molecular	circuits
pink	world
solar	equation
monkey	biologists
nonscientist	slip
materialist	harbor

5. Physicists Aim to Classify All Possible Phases of Matter

Part 1

Exercise I.

Say what Russian words help to guess the meaning of the following classify, decades, exotic, phases, gases, theoretical, absolute, temperature, experiments, situations

Exercise II

Make sure you know the following words and word combinations.
condensed matter physics, frigid, to shed, en mass, trail, to swirl, fractal, braid, stride, swatch, fractional quantum Hall effect,

Physicists Aim to Classify All Possible Phases of Matter

In the last three decades, condensed matter physicists have discovered a wonderland of exotic new phases of matter: emergent, collective states of interacting particles that are nothing like the solids, liquids and gases of common experience (1)

The phases, some realized in the lab and others identified as theoretical possibilities, arise when matter is chilled almost to absolute-zero temperature, hundreds of degrees below the point at which water freezes into ice. In these frigid conditions, particles can interact in ways that cause them to shed all traces of their original identities. Experiments in the 1980s revealed that in some situations electrons split en masse into fractions of particles that make braidable trails through space-time; in other cases, they collectively whip up massless versions of themselves. A lattice of spinning atoms becomes a fluid of swirling loops or branching strings; crystals that began as insulators start conducting electricity over their surfaces. One phase that shocked experts when recognized a mathematical possibilit features strange, particle-like “fractons” that lock together in fractal patterns. Now, research groups at Microsoft and elsewhere are racing to encode quantum information in the braids and loops of some of these phases for the purpose of developing a quantum computer. Meanwhile, condensed matter theorists have recently made major strides in understanding the pattern behind the different collective behaviors that can arise, with the goal of enumerating and classifying all possible phases of matter. If a complete classification is achieved, it would not only account for all phases seen in nature so far, but also potentially point the way toward new materials and technologies. Led by dozens of top theorists, with input from mathematicians, researchers have already classified a huge swath of phases that can arise in one or two spatial dimensions by relating them to topology: the math that describes invariant properties of shapes like the sphere and the torus. They’ve also begun to explore the wilderness of phases that can arise near absolute zero in 3-D matter. “It’s not a particular law of physics” that these scientists seek, said Michael Zaletel, a condensed matter theorist at Princeton University. “It’s the space of all possibilities, which is a more beautiful or deeper idea in some ways.” Perhaps surprisingly, Zaletel said, the space of all consistent phases is itself a mathematical object that “has this incredibly rich structure that we think ends up, in 1-D and 2-D, in one-to-one correspondence with these beautiful topological structures." In the landscape of phases, there is "an economy of options," said Ashvin Vishwanath of Harvard University. "It all seems comprehensible" — a stroke of luck that mystifies him. Enumerating phases of matter could have been "like stamp collecting," Vishwanath said, "each a little different, and with no connection between the different stamps." Instead, the classification of phases is "more like a periodic table. There are many elements, but they fall into categories and we can understand the categories." While classifying emergent particle behaviors might not seem fundamental, some experts, including Xiao-Gang Wen of the Massachusetts Institute of Technology, say the new rules of emergent phases show how the elementary particles themselves might arise from an underlying network of entangled bits of quantum information, which Wen calls the "qubit ocean." For example, a phase called a "string-net liquid" that can emerge in a three-dimensional system of qubits has excitations that look like all the known elementary particles. "A real electron and a real photon are maybe just fluctuations of the string-net," Wen said. (2)

Before these zero-temperature phases cropped up, physicists thought they had phases all figured out. By the 1950s, they could explain what happens when, for example, water freezes into ice, by describing it as the breaking of a symmetry: Whereas liquid water has rotational symmetry at the atomic scale (it looks the same in every direction), the H20 molecules in ice are locked in crystalline rows and columns. Things changed in 1982 with the discovery of phases called fractional quantum Hall states in an ultracold, two-dimensional gas of electrons. These strange states of matter feature emergent particles with fractions of an electron's charge that take fractions of steps in a one-way march around the perimeter of the system. "There was no way to use different symmetry to distinguish those phases," Wen said. A new paradigm was needed. In 1989, Wen imagined phases like the fractional quantum Hall states arising not on a plane, but on different topological manifolds — connected spaces such as the surface of a sphere or a torus. Topology concerns global, invariant properties of such spaces that can't be changed by local deformations. Famously, to a topologist, you can turn a doughnut into a coffee cup by simply deforming its surface, since both surfaces have one hole and are therefore equivalent topologically. You can stretch and squeeze all you like, but even the most malleable doughnut will refuse to become a pretzel. Wen found that new properties of the zero-temperature phases were revealed in the different topological settings, and he coined the term "topological order" to describe the essence of these phases. Other theorists were also uncovering links to topology. With the discovery of many more exotic phases — so many that researchers say they can barely keep up — it became clear that topology, together with symmetry, offers a good organizing schema. The topological phases only show up near absolute zero, because only at such low temperatures can systems of particles settle into their lowest-energy quantum "ground state." In the ground state, the delicate interactions that correlate particles' identities — effects that are destroyed at higher temperatures — link up particles in global patterns of quantum entanglement. Instead of having individual mathematical descriptions, particles become components of a more complicated function that describes all of them at once, often with entirely new particles emerging as the excitations of the global phase. The long-range entanglement patterns that arise are topological, or impervious to local changes. Consider the simplest topological phase in a system — called a "quantum spin liquid" — that consists of a 2-D lattice of "spins," or particles that can point up, down, or some probability of each simultaneously. At zero temperature, the spin liquid develops strings of spins that all point down, and these strings form closed loops. As the directions of spins fluctuate quantum-mechanically, the pattern of loops throughout the material also fluctuates: Loops of down spins merge into bigger loops and divide into smaller loops. In this quantum-spin-liquid phase, the system's ground state is the quantum superposition of all possible loop patterns. To understand this entanglement pattern as a type of topological order, imagine, as Wen did, that the quantum spin liquid is spilling around the surface of a torus, with some loops winding around the torus's hole. Because of these hole windings, instead of having a single ground state associated with the superposition of all loop patterns, the spin liquid will now exist in one of four distinct ground states, tied to four different superpositions of loop patterns. One state consists of all possible loop patterns with an even number of loops winding around the torus's hole and an even number winding through the hole. Another state has an even number of loops around the hole and an odd number through the hole; the third and fourth ground states correspond to odd and even, and odd and odd, numbers of hole windings, respectively. Which of these ground states the system is in stays fixed, even as the loop pattern fluctuates locally. If, for instance, the spin liquid has an even number of loops winding around the torus's hole, two of these loops might touch and combine, suddenly becoming a loop that doesn't wrap around the hole at all. Long-way loops decrease by two, but the number remains even. The system's ground state is a topologically invariant property that withstands local changes. (3)

Future quantum computers could take advantage of this invariant quality. Having four topological ground states that aren't affected by local deformations or environmental error "gives you a way to store quantum information, because your bit could be what ground state it's in," explained Zaletel, who has studied the topological properties of spin liquids and other quantum phases. Systems like spin liquids don't really need to wrap around a torus to have topologically protected ground states. A favorite playground of researchers is the toric code, a phase theoretically constructed by the condensed matter theorist Alexei Kitaev of the California Institute of Technology in 1997 and demonstrated in experiments over the past decade. The toric code can live on a plane and still maintain the multiple ground states of a torus. (Loops of spins are essentially able to move off the edge of the system and re-enter on the opposite side, allowing them to wind around the system like loops around a torus's hole.) "We know how to translate between the ground-state properties on a torus and what the behavior of the particles would be," Zaletel said. Spin liquids can also enter other phases, in which spins, instead of forming closed loops, sprout branching networks of strings. This is the string-net liquid phase that, according to Wen, "can produce the Standard Model" of particle physics starting from a 3-D qubit ocean. (4)

Adapted from Quanta Magazine.

Exercise III.

Find paragraphs, dealing with the following: strides, braidable, toric, re-enter, massless, freeze , traces, fluid, encode, swath

Exercise IV.

Fill in the gaps.

1. Water is a bottom-up, self-organized …….. property of hydrogen and oxygen.
2. In Romania, local media reported four people had died due to the …………. weather.
3. Only a tiny ……… of imports are inspected at all, and even fewer are tested.
4. The most incomprehensible thing about the universe is that it is …………...
5. Sometimes their works evoke strong emotions or ………… readers with metaphysical philosophy.
6. One way to make a ……….. is to trap a single electron in semiconductor material.
7. The reasons for their opposition to the protest movement are ………, said Yusef.
8. If these are counted, centipedes actually have an ……….. of trunk segments.
9. High-speed rail would …………… air pollutants …… keeping more cars off the road.
10. Place the tray in a sunny window, and the seeds should ……… within a few days.

Exercise V .

Make up sentences of your own with the following word combinations:

to whip up (1), to conduct electricity(1), to make major strides in (1),to fall into (1), to freeze into ice (2), at the atomic scale (2), to look the same (2), in every direction(2), to decrease by..., to coin the term (3)

Exercise VI.

Determine whether the statements are true or false. Correct the false statements:

1. In the last three decades, condensed matter physicists have discovered a wonderland of exotic new phases of matter: emergent, collective states of interacting particles that are like the solids, liquids and gases of common experience
2. The phases, some realized in the lab and others identified as theoretical possibilities, arise when matter is chilled almost to absolute-zero temperature, hundreds of degrees below the point at which water freezes into ice.
3. Experiments in the 1980s revealed that in some situations electrons split en masse into fractions of particles that make braidable trails through space-time; in other cases, they collectively whip up massless versions of themselves.
4. A lattice of spinning atoms becomes a fluid of swirling loops or branching strings; crystals that began as insulators stop conducting electricity over their surfaces.
5. One phase that shocked experts when recognized as a mathematical possibility features strange, particle-like “fractons” that lock together in fractal patterns.
6. Now, research groups at Microsoft and elsewhere are racing to encode quantum information in the braids and loops of some of these phases for the purpose of developing a quantum computer.

7. Meanwhile, condensed matter theorists have recently made major strides in understanding the pattern behind the different collective behaviors that can arise, with the goal of enumerating and classifying all possible phases of matter.
8. If a complete classification is achieved, it would not only account for all phases seen in nature so far, but also potentially point the way toward new materials and technologies.
9. Led by dozens of top theorists, with input from mathematicians, researchers have already classified a huge swath of phases that can arise in one spatial dimension by relating them to topology: the math that describes invariant properties of shapes like the sphere and the torus.
10. A phase called a "string-net liquid" that can emerge in a two-dimensional system of qubits has excitations that look like all the known elementary particles.

Exercise VII .

Match the words to the definitions in the column on the right:

qubit	to change or vary frequently between one level or thing and another
march	to be strong enough, or not bechanged by something, or to oppose aperson or thing successfully
manifold	to begin to grow, or to produce new growth
to squeeze	any stage in a series of events or in aprocess of development
to fluctuate	starting to exist or to become known
phase	a small part of something, or a small amount
to withstand	a quantum bit, the equivalent in quantum computing to

	the binary digit or bit of classical computing
to sprout	the continuous development of a state, activity, or idea
emergent	many and of different types
fraction	to press something firmly, especially from all sides in order to change its shape, reduce its size, or remove liquidfrom it

Exercise VIII .

Summarize the article “Physicists Aim to Classify All Possible Phases of Matter”

Part 2

Exercise I.

Identify the part of speech the words belong to.

emergent, fraction, insubator, wilderness, comprehensible, mystify, fluctuation, excitation, impervious, experience

Exercise II .

Form nouns from the following words:

classify (1), discover (1), interact (1), emergent (1), realize (2), identify (2), theoretical (2), original (2), conduct (2), mathematical (2)

Exercise III.

Find synonyms to the following words. Translate them into Russian: phase (1), aim (1), arise (2), huge (2), split (2), reveal (2), electricity (2), achieve (2), top (2), explore (2)

Exercise IV.

Find antonyms to the following words. Translate them into Russian: exotic (1), collective (1), major (2), frigid (2), start (2), surface (2), expert (2), complete (2), new (2), odd number (3)

Exercise V.

Match the words to make word combinations:

condensed	patterns
spatial	matter
research	temperature
topological	schema
string-net	conditions
even	dimensions
absolute-zero	liquid
malleable	groups
frigid	number
fractal	order

SUPPLEMENTARY READING

1. The idea that everything from spoons to stones is conscious is gaining academic credibility

Consciousness permeates reality. Rather than being just a unique feature of human subjective experience, it's the foundation of the universe, present in every particle and all physical matter.

This sounds like easily-dismissible bunkum, but as traditional attempts to explain consciousness continue to fail, the "panpsychist" view is increasingly being taken seriously by credible philosophers, neuroscientists, and physicists, including figures such as neuroscientist Christof Koch and physicist Roger Penrose.

"Why should we think common sense is a good guide to what the universe is like?" says Philip Goff, a philosophy professor at Central European University in Budapest, Hungary. "Einstein tells us weird things about the nature of time that counters common sense; quantum mechanics runs counter to common sense. Our intuitive reaction isn't necessarily a good guide to the nature of reality."

David Chalmers, a philosophy of mind professor at New York University, laid out the "hard problem of consciousness" in 1995, demonstrating that there was still no answer to the question of what causes consciousness. Traditionally, two dominant perspectives, materialism and dualism, have provided a framework for solving this problem. Both lead to seemingly intractable complications.

The materialist viewpoint states that consciousness is derived entirely from physical matter. It's unclear, though, exactly how this could work. "It's very hard to get consciousness out of non-consciousness," says Chalmers. "Physics is just structure. It can explain biology, but there's a gap: Consciousness." Dualism holds that consciousness is separate and distinct from physical matter—but that then raises the question of how consciousness interacts and has an effect on the physical world.

Panpsychism offers an attractive alternative solution: Consciousness is a fundamental feature of physical matter; every single particle in existence has an "unimaginably simple" form of consciousness, says Goff. These particles then come together to form more complex forms of consciousness, such as humans' subjective experiences. This isn’t meant to imply that particles have a coherent worldview or actively think, merely that there’s some inherent subjective experience of consciousness in even the tiniest particle.

Panpsychism doesn’t necessarily imply that every inanimate object is conscious. “Panpsychists usually don’t take tables and other artifacts to be conscious as a whole,” writes Hedda Hassel Mørch, a philosophy researcher at New York University’s Center for Mind, Brain, and Consciousness, in an email. “Rather, the table could be understood as a collection of particles that each have their own very simple form of consciousness.”

But, then again, panpsychism could very well imply that conscious tables exist: One interpretation of the theory holds that “any system is conscious,” says Chalmers. “Rocks will be conscious, spoons will be conscious, the Earth will be conscious. Any kind of aggregation gives you consciousness.”

Interest in panpsychism has grown in part thanks to the increased academic focus on consciousness itself following on from Chalmers’ “hard problem” paper. Philosophers at NYU, home to one of the leading philosophy-of-mind departments, have made panpsychism a feature of serious study. There have been several credible academic books on thesubject in recent years, and popular articles taking panpsychism seriously.

One of the most popular and credible contemporary neuroscience theories on consciousness, Giulio Tononi’s Integrated Information Theory, further lends credence to panpsychism. Tononi argues that something will have a form of “consciousness” if the information contained within the structure is sufficiently “integrated,” or unified, and so the whole is more than the sum of its parts. Because it applies to all structures—not just the human brain—Integrated Information Theory shares the panpsychist view that physical matter has innate conscious experience.

Goff, who has written an academic book on consciousness and is working on another that approaches the subject from a more popular-science perspective, notes that there were credible theories on the subject dating back to the 1920s. Thinkers including philosopher Bertrand Russell and physicist Arthur Eddington made a serious case for panpsychism, but the field lost momentum after World War II, when philosophy became largely focused on analytic philosophical questions of language and logic. Interest picked up again in the 2000s, thanks both to recognition of the “hard problem” and to increased adoption of the structural-realist approach in physics, explains Chalmers. This approach views physics as describing structure, and not the underlying nonstructural elements.

“Physical science tells us a lot less about the nature of matter than we tend to assume,” says Goff. “Eddington”—the English scientist who experimentally confirmed Einstein’s theory of general relativity in the early 20th century—“argued there’s a gap in our picture of the universe. We know what matter does but not what it is. We can put consciousness into this gap.”

In Eddington’s view, Goff writes in an email, it’s “”silly” to suppose that that underlying nature has nothing to do with consciousness and then to wonder where consciousness comes from.” Stephen Hawking haspreviously asked: “What is it that breathes fire into the equations and makes a universe for them to describe?” Goff adds: “The Russell-Eddington proposal is that it is consciousness that breathes fire into the equations.”

The biggest problem caused by panpsychism is known as the “combination problem”: Precisely how do small particles of consciousness collectively form more complex consciousness? Consciousness may exist in all particles, but that doesn’t answer the question of how these tiny fragments of physical consciousness come together to create the more complex experience of human consciousness. Any theory that attempts to answer that question, would effectively determine which complex systems—from inanimate objects to plants to ants—count as conscious.

An alternative panpsychist perspective holds that, rather than individual particles holding consciousness and coming together, the universe as a whole is conscious. This, says Goff, isn’t the same as believing the universe is a unified divine being; it’s more like seeing it as a “cosmic mess.” Nevertheless, it does reflect a perspective that the world is a top-down creation, where every individual thing is derived from the universe, rather than a bottom-up version where objects are built from the smallest particles. Goff believes quantum entanglement—the finding that certain particles behave as a single unified system even when they’re separated by such immense distances there can’t be a causal signal between them—suggests the universe functions as a fundamental whole rather than a collection of discrete parts.

Such theories sound incredible, and perhaps they are. But then again, so is every other possible theory that explains consciousness. “The more I think about [any theory], the less plausible it becomes,” says Chalmers. “One starts as a materialist, then turns into a dualist, then a panpsychist, then an idealist,” he adds, echoing his paper on the subject. Idealism holds that physical matter does not exist at all and conscious experience is the only thing there is. From that perspective, panpsychism is quite moderate.

Chalmers quotes his colleague, the philosopher John Perry, who says: “If you think about consciousness long enough, you either become a panpsychist or you go into administration.”

Adapted from Quartz.

2. It’s not all lightbulbs

If we abandon the cult of the Great White Innovator, we will understand the history of technology in a much deeper way

Innovation has become a defining ideology of our time. Be disruptive, move fast, break things! And everyone knows – right? – what innovation looks like. Just Google the word. You’ll see lots of lightbulbs. Lightbulbs represent a sudden flash of inventiveness experienced by Thomas Edison or other mythic geniuses.

Innovation, as an infinite progression of advertisements, political campaigns and university incubators tell us, is Always A Very Good Thing. And, like all myths, this one holds some truth. Technological innovation has raised standards of living, made populations healthier, safer and smarter.

But, in large part because this isn’t always true, it’s essential to understand how science and technology advances actually happen and affect the world. Because of their importance, it’s essential to reflect more critically on our collective myths about innovation.

First, forget all those images that a web search gives. The driving forces of innovation are not mythic isolated geniuses, almost always represented as men, be it Edison or Steve Jobs. That view is at best misleading, the history of technology and science’s version of the Great (White) Man approach to history. For instance, Edison almost never worked alone. The more than 2 billion smartphones used around the world today function not because of Jobs’s singular genius, not even because of the private sector, but because of research and development funded by an entrepreneurial state.

The history of technology is too important to be left to the technologists. Relying on PayPal’s founders Elon Musk or Peter Thiel to tell us how that history goes is like turning to Bill Clinton or Newt Gingrich to tell the political history of the 1990s. Books such as Walter Isaacson’s The Innovators(2014) or Steven Johnson’s How We Got to Now (2015) give us accounts of lone genius men toiling in industrial labs and Bay Area garages. This view of innovation – narrow and shallow – casts a long shadow, one that obscures the broad and deep currents that actually drive technological innovation and shape its impact on society.

Instead, consider the Otts. Somewhere in Kansas during the early years of the Great Depression, Bill Ott and his daughter Lizzie did something different with their car. By removing the rear tyre and adding a drive belt, they built a homemade car-powered washing machine. As an ‘innovation thought leader’ at Davos or TED might say, the Otts hacked the automobile and re-invented the washing machine. Stated simply – they innovated. So how come you haven’t heard of the Otts? Because the Great White Man narrative of innovation ignores the critical role that anonymous, unrecognised people such as Bill and Lizzie Ott play in the incrementalism that is the real stuff of technological change. Most of the time, innovators don’t move fast and break things.

Over the past two centuries, almost all professional scientists and engineers have worked not to cut down the old trees of technologies and knowledge and grow new ones, but to nurture and prune the existing ones. In corporate-based science and technology, disruption is very rare, continuity rules, and makes change and advance possible. At different times in history, such disruption was even discouraged. At the great industrial labs of the early 20th century, companies such as General Electric (GE) or AT&T didn’t want their engineers and scientists to create excessive technological novelty – tens of millions of company dollars had been invested to build existingtechnological systems. Instead, research managers such as Willis R Whitney, head of GE’s research, sought incremental improvements that would marginally advance the company’s technologies and extend its intellectual property regime. Kenneth C Mees, who ran Kodak’s research lab for decades, noted in 1920 that corporate research managers did not seek brilliant, eccentric (and unpredictable) geniuses. Provided that a researcher was well-trained, anyone could make a contribution to research ‘even though he be entirely untouched by anything that might be considered the fire of genius’.

As we redefine our sense of what an innovator is and what talents she might possess, we start to see that the industrial revolutions of the past few centuries did not have one single global meaning. The economic reshuffling, social upheaval and environmental exploitation of modern industrial revolutions look very different from the perspective of a person living in Europe than from the perspective of people in Asia or Africa, for example. If we leave the shadow of the cult of the Great White Innovator theory of historical change, we can see farther, and deeper.

The global view shifts the focus from Manchester, Lowell, Detroit and Silicon Valley. It involves accepting that innovation and technological change are more than just making things. Ironically, this allows us to begin to glimpse a more familiar world where activities such as maintenance, repair, use and re-use, recycling, obsolescence and disappearance dominate. A much more global picture, one that includes people whose lives and contributions the Great White Innovator narrative marginalised, comes into view. The Lizzie Otts of the world can take their proper place as participants and contributors.

Every year, I teach a course on the history of technology. At the start of the each term, I ask my students at the University of California to finish this sentence: ‘Technology is…?’

The responses are predictable. To most undergraduates, technology means the machines and devices around them – cars, laptops, smart phones and, yes, lightbulbs. At the end of term, I ask them the question again. If I’m lucky and have taught a good course, my students will have come to understand that technology is more than just things. It’s more complex and richer than just the machines around them. It includes things we don’t typically think ofas things, such as patents, regulations, professional accreditations and, of course, the institutions that make these things.

Take one example – technical standards. When you go to the hardware store and buy a screw to replace one that’s broken, you probably feel pretty confident that when the label says a ‘3/8 metal screw with 32 threads per inch’, that’s what you’re getting. That’s because American and European bureaucrats and engineers worked for decades to establish standards. Without these, interchangeable parts and global trade would have been practically impossible. Largely ignored, often invisible, standards created stability in technological systems. Whether it’s screws or shipping containers, standards transformed the novel into the mundane, and made the local into the global.
Making standards wasn’t about making new material objects exactly. Establishing standards meant making consensus via some sort of political process. For screw threads – a mundane, possibly quite boring example –

this required a series of national and international meetings, and input from professional engineering societies (itself somewhat of an ‘innovation’ as engineers in the US and overseas began to organise themselves politically). The goal wasn’t disruption and moving fast but rather reaching agreement and creating technological stability. This political engineering sometimes meant overcoming complaints that the standards promoted by large companies such as AT&T stifled innovation and further centralised its corporate power. It took the action of national organisations to override resistance. In 1924, the president of the American Standards Association argued that standards were ‘the liberator’ that relegated problems that had already been solved to the realm of the routine.

As political artefacts, standards embody certain ideologies. For the internet, it is an aspiration towards openness – open systems, open access, open source. In the US, this ideology has deep historical roots. Some ideas inherent in this openness can be traced from the civil liberties driving resistance towards England’s Stamp Act in the mid-18th century to 20th-century ideals of open societies as alternatives to fascist and communist regimes. The philosopher Langdon Winner argued in 1980 that artefacts have politics, beliefs and assumptions about the world and society that are embedded and written into their very fabric.

As a result, technical standards – the very ‘things’ that allow my laptop and your iPhone to seamlessly (more or less) connect to networks as we move about the planet – requires the International Organization of Standardization (ISO), as well as recognition and cooperation from state agencies such as the US Federal Communications Commission or the International Telecommunication Union. Techno-libertarians might claim ‘I made it’ but the reality is that, without international standards, whatever they made wouldn’t work very well.

Core ideas and beliefs are additional ‘things’ that underpin our technological world. Central among these is a pervasive ideology – the quest for efficiency – that runs throughout past and present industrial revolutions. The quest for greater efficiency and rational operations flowed from the automatic flour mill that Oliver Evans patented in 1790 to the stopwatch-obsessed scientific managers who applied their techniques to the management of factory and home. The ideal of Frederick Winslow Taylor’s quest for a ‘one best way’ continued into 1960s-era modernisation plans in the world’s poor regions. Capitalist and communist systems alike embraced it, competing to outdo one another in productivity and efficiency. This same ideal burns bright in today’s descriptions of a forthcoming ‘Fourth Industrial Revolution’, where the cyber and physical worlds are linked.

At the beginning of Joseph Conrad’s novel Heart of Darkness (1902), Marlow holds forth on what distinguishes the British empire from its predecessors or rival imperialists. ‘What saves us is efficiency,’ he claims, ‘the devotion to efficiency.’ Conrad wrote his book when machines were the measure of a culture. Efficiency enabled the civilised to control the savage. A beacon for industrial revolutions, a devotion to efficiency illuminated the path from the waterwheel to social control and, in Britain’s case, to an unprecedented global empire.

Efficiency, therefore, is not some timeless universal value but something grounded deeply in particular historical circumstances. At various times, efficiency was a way of quantifying machine performance – think: steam engines – and an accounting principle coupled to the new applied sciences of mechanics and thermodynamics. It was also about conservation and stability. By the early 20th century – the apogee of Taylorism – experts argued that increases in efficiency would realise the full potential of individuals and industries. Dynamism and conservatism worked together in the pursuit of ever-greater efficiency.

But a broad look at the history of technology plainly shows that other values often take precedence over efficiency, even in the modern era. It would, for example, offer several advantages in efficiency if, instead of every apartment or home having its own kitchen, multiple families shared a communal kitchen, and indeed in some parts of the world they do. But in the prevalent ideology of domesticity, every family or even single person must have their own kitchen, and so it is.

Nor, despite what Silicon Valley-based techno-libertarians might argue, does technological change automatically translate to increased efficiency. Sometimes, efficiency – like the lone eccentric innovator – is not wanted. In the 1960s, for instance, the US military encouraged metal-working firms, via its contracting process, to adopt expensive numerically controlled machine tools. The lavish funding the Department of Defense devoted to promoting the technology didn’t automatically yield clear economic advantages. However, the new machines – ones that smaller firms were hard-pressed to adopt – increased centralisation of the metalworking industry and, arguably, diminished economic competition. Meanwhile, on the shop floor, the new manufacturing innovations gave supervisors greater oversight over production. At one large manufacturing company, numerical control was referred to as a ‘management system’, not a new tool for cutting metal. Imperatives besides efficiency drove technological change.

The history of technological change is full of examples of roads not taken. There are many examples of seemingly illogical choices made by firms and individuals. This shouldn't surprise us – technological change has always been a deep and multilayered process, one that unfolds in fits and starts and unevenly in time and space. It's not like the 'just so stories' of pop history and Silicon Valley public relations departments.

Although technology is most assuredly not just things, there's no denying its fundamental materiality. The physical reality of technologies settles over time, like sediment. Over time, technologies, like mountains or old cities, form layers that a geologist might conjure and a historian can try to understand. Technologies stack.

As the historian of computing Nathan Ensmenger puts it, geography shapes technology and vice versa. In the early 20th century, the Southern Pacific was one of the largest railroad companies in the US. By 1930, the company and its subsidiaries operated more than 13,000 miles of track. In the 1970s, a unit of Southern Pacific maintained a series of microwave communication towers along its railway lines. Microwave communications gave way to a network of fibre-optic cables laid along railway tracks. Around 1978, the Southern Pacific Communications Company began providing a long-distance phone service. When this split from the larger railroad company, the firm needed a new name. The choice was Southern Pacific Railroad Internal Network Telecommunications. With its original infrastructure built on 19th-century railroad lines, SPRINT got to be one of the largest wireless service providers in the US by incremental change and layers built on top of layers.

As they layer and stack, technologies persist over time. For instance, 19th-century Japan was a world where steam and sail, railroads and rickshaws all shared common space. Industrial revolutions were distributed unequally in place and time. In the Second World War, the most common transport for the German army wasn't tanks and other motorised vehicles but horses. The technological world wasn't flat. This is the world, still, today. It is lumpy and bumpy, with old and new technologies accumulating on top of and beside each other.

Our prevailing focus on the shock of the technological new often obscures or distorts how we see the old and the preexisting. It's common to hear how the 19th-century telegraph was the equivalent of today's internet. In fact, there's a bestseller about it, The Victorian Internet (1998) by Tom Standage. Except this isn't true. Sending telegrams 100 years ago was too expensive for most people. For decades, the telegraph was a pricey, elite technology.

However, what was innovative for the majority of people c1900 was cheap postage. So, during the heyday of the so-called Victorian internet, transoceanic postal systems made communication cheap, reliable and fast. The flow of information grew significantly more accessible and democratic. Although hard to imagine today, bureaucrats and business leaders alike spoke about cheap postage in laudatory terms that resemble what we hear for many emerging technologies today. By not seeing these older technologies in the past, we stand in danger of ignoring the value and potential of technologies that exist now in favour of those about to be. We get, for instance, breathless stories about Musk’s Hyperloop and neglect building public transport systems based on existing, proven technologies or even maintaining the ones we have.

If we maintain a narrow and shallow view of innovation, notions of making (new) stuff too easily predominate. In the 1880s, the insurance executive-turned-entrepreneur George Eastman and his colleagues invented new types of photographic film. This film was easier to use and develop but, still, sales were stagnant. Then Eastman had the idea of going for the untapped market of people who wanted to try photography but found it intimidating. In 1888, Eastman’s company introduced the Kodak camera with the slogan: ‘You press the button, we do the rest.’ For $25 – a large sum in 1890 – one could buy a camera preloaded with 100 exposures. When done, the amateur photographer simply sent the camera to Eastman Kodak where the film was removed and processed, while the developed pictures, along with the camera re-loaded with fresh film, were sent back. More than inventing a new camera, Eastman’s company invented a new community of users – amateur photographers. And, of course, Eastman’s entrepreneurial initiative would have been impossible without the existence of a robust government-created postal network. His system stacked on top of an existing one just as much of today’s ‘disruptive innovation’ relies on the internet.

Today, this same narrowness persists in popular perceptions of what a ‘technology company’ is. As Ian Bogost recently noted in The Atlantic, the ‘technology’ in the tech sector is typically restricted to computer-related companies such as Apple and Alphabet while the likes of GE, Ford or Chevron are overlooked. This is absurd. Surely Boeing – which makesthings – is a ‘tech company’, as is Amazon, which delivers things using Boeing’s things. Revising our sense of what technology is – or who does innovation – reshapes and improves our understanding of what a technology company is.

One cause of this confusion, I believe, stems from our decades-long fascination with Silicon Valley: once a romance, it now has all the hallmarks of a dysfunctional relationship. Just as ‘computer’ is a synecdoche for ‘technology’, Silicon Valley has come to reflect a certain monoculture of thought and expression about technology. One must tread carefully here, of course. Just as the medieval Catholic Church or the Cold War Kremlin were not monolithic entities, there is not one single Silicon Valley. Rather, it’s a complex assemblage of workers, managers, investors, engineers, et al. Unfortunately, some technology pundits ignore this diversity and reduce Silicon Valley to a caricature landscape of disruptive startups.

Ironically, many high-tech intellectuals present an extreme perspective of technology that rejects its ‘thinginess’. A persistent flaw in today’s digital boosterism is forgetting that all the stuff that makes the internet and the web work is actually made of something – silicon, plastic, rare-earth minerals mined in Bolivia or China. The Foxconn workers in Shenzhen who assemble iPhones and other high-tech devices certainly see it that way. Popular terminology – the ‘Cloud’ being the most pernicious – obscures the undeniable (but not all-encompassing) materiality of technology. So domaps of the internet that represent its complex physical infrastructure as a network of disembodied nodes and flowcharts.

Perhaps most simply, what you will almost never hear from the tech industry pundits is that innovation is not always good. Crack cocaine and the AK-47 were innovative products. ISIS and Los Zetas are innovative organisations. Historians have long shown that innovation doesn’t even always create jobs. It sometimes destroys them. Automation and innovation, from the 1920s through the 1950s, displaced tens of thousands of workers. Recall the conflict between Spencer Tracy (a proponent of automation) and Katharine Hepburn (an anxious reference librarian) in the film Desk Set(1957).

And what of broader societal benefits that innovation brings? InTechnological Medicine (2009), Stanley Joel Reiser makes a compelling case that, in the world of healthcare, innovation can bring gains and losses – and the winners are not always the patients. The innovation of the artificial respirator, for example, has saved countless lives. It has also brought in new ethical, legal and policy debates over, literally, the meaning of life and death. And there are real questions about the ethics of resource expenditure in medical innovation. Can spending large amounts pursuing innovative treatments or cures for exotic, rare diseases be ethical when the same monies could without question save millions of lives afflicted with simple health challenges?

It’s unrealistic to imagine that the international obsession with innovation will change any time soon. Even histories of nation-states are linked to narratives, rightly or wrongly, of political and technological innovation and progress. To be sure, technology and innovation have been central drivers of the US's economic prosperity, national security and social advancement. The very centrality of innovation, which one could argue has taken on the position of a national mantra, makes a better understanding of how it actually works, and its limitations, vital. Then we can see that continuity and incrementalism are a much more realistic representation of technological change.

At the same time, when we step out of the shadow of innovation, we get new insights about the nature of technological change. By taking this broader perspective, we start to see the complexity of that change in new ways. It's then we notice the persistent layering of older technologies. We appreciate the essential role of users and maintainers as well as traditional innovators such as Bill Gates, Steve Jobs, and, yes, Bill and Lizzie Ott. We start to see the intangibles – the standards and ideologies that help to create and order technology systems, making them work at least most of the time. We start to see that technological change does not demand that we move fast and break things. Understanding the role that standards, ideologies, institutions – the non-thing aspects of technology – play, makes it possible to see how technological change actually happens, and who makes it happen. It makes it possible to understand the true topography of technology and the world today.

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